AC 2007-2321: COLLABORATIVE DESIGN OF PROJECT-BASED LEARNING COURSES: HOW TO IMPLEMENT A MODE OF LEARNING THAT EFFECTIVELY BUILDS SKILLS FOR THE GLOBAL ENGINEER

Richard Savage, California Polytechnic State University

Linda Vanasupa, California Polytechnic State University

Jonathan Stolk, Franklin W. Olin College of Engineering

Collaborative design of project-based learning courses: How to implement a mode of learning that effectively builds skills for the global engineer

Abstract

Success for tomorrow's engineers necessitates the design of curricula that promote awareness of the broader impacts of engineering, enhances systems thinking, reflects sustainable engineering practices, and helps prepare students to make an impact in the global community. Project-based learning approaches that emphasize student learning rather than instructor teaching may be a key to successful development of "global engineers." Evaluations of project-based courses show increases in student motivation, problem-solving ability, communication and teaming skills, knowledge retention, and capacity for self-directed learning. Despite these reported benefits, curriculum-wide implementations of project-based learning are rare, probably partly due to the traditional emphasis on technical content acquisition in upper-level courses and a lack of clear methods for ensuring that core competencies are not lost through the project-based mode of learning. To better equip students to be successful global engineers, we recently initiated a large-scale transformation of our undergraduate materials engineering curriculum. The redesign includes a major change in the junior year from traditional subject-based courses to project-based courses facilitated by faculty teams. In the new approach, the learning of fundamental materials engineering content is driven by a series of authentic, hands-on projects. In this paper, we describe a collaborative faculty process for the systematic design of project-based courses for disciplinary core competencies. It involves developing a shared understanding of the vision and goals, identifying user needs and values, articulating and grouping the disciplinary core competencies (knowledge, skills, and attitudes), and designing the project-based experience through an iterative process of embedding core competencies and mapping the experience back to the user needs. We will draw upon our experience in converting the entire junior-year sequence in materials engineering at Cal Poly (12 separate courses) to a project-based learning mode. We briefly discuss the challenges we faced during the transition to the new approach, and provide an overview of the initial student responses to the new learning environment and an assessment of their performance.

Cal Poly Materials Engineering Mission & Vision

The primary mission of the Department of Materials Engineering at Cal Poly is to prepare students to be successful as global engineers. Our vision is to equip engineers to solve technical challenges in the context of a complex global society. Our strategy is to redesign our entire Materials Engineering undergraduate curriculum and promote self-directed learning (SDL), systems-level thinking and sustainable engineering practices. Moreover, we plan to develop a pedagogy that challenges students to balance economic, societal and environmental issues when striving to achieve design solutions based on the fundamental principles of material processing, structure and properties. We refer to this as the Triple Bottom Line Awareness in Design or TriAD.

We believe that project-based learning (PBL) experiences that emphasize student learning rather than instructor teaching can play a key role in the successful development of a "global engineer." Evaluations of project-based courses show increases in student motivation, problem-solving ability, communication and teaming skills, knowledge retention, and capacity for self-directed learning[1]. Despite these reported benefits, curriculum-wide implementations of project-based learning are rare, probably partly due to the traditional emphasis on technical content in upper-level courses and a lack of clear methods for ensuring that core competencies are not lost through the project-based mode of learning. In this report, we will share the methodologies that we have developed and adopted for implementing PBL throughout our entire undergraduate curriculum.

A Project-based Learning Curriculum

At Cal Poly, we have had a long tradition of utilizing active-learning techniques; about one-half (53-percent) of the hours in materials engineering courses are spent in a laboratory setting. However, over the past two years we have initiated a large-scale transformation of our undergraduate materials engineering curriculum from a lecture/lab based format to a format where approximately 80% of our courses are based on active-learning pedagogy[2-9]. This redesign involves a major change from traditional subject-based courses to project-based and problem-based courses facilitated by faculty teams. In the new project-based courses, the learning of fundamental materials engineering content is driven by a series of authentic, hands-on projects. These projects challenge students to design products that meet user's needs, develop design solutions based on a systems-level perspective and evaluate design performance through prototype fabrication and testing. Students also experience the broader impacts of their design solutions by completing service-learning projects that benefit the local community.

The projects provide students with a context for learning. They give them a reason to see why and how the fundamental principles of science, math and engineering can be utilized to solve practical design problems. Traditionally, the educational process involves students first learning the fundamentals and then utilizing "total recall" to apply these facts to solve a problem; learning objectives are set by the instructor and principles are presented to the students through lectures. Assignments are given to reinforce the application of the concepts, but often students merely "learn" what is necessary to pass the test or "repeat-back" information to satisfy the instructor[10]. In contrast, the PBL approach employs a problem as the driving force for learning the fundamental principles that are required to find a solution. Moreover, this approach provides a context that makes learning the fundamentals more relevant and, hence, results in better retention by students[11]. For clarity, we view problem-based learning as pertaining to the development of knowledge based on the fundamental principles of science and mathematics and project-based learning to include mastering the engineering skills required to implement a design solution.

A key result of all of the PBL activities is to enable students to develop self-directed learning capabilities. After all, the purpose of education is not to transmit "what to know" but to challenge students to develop the skills of inquiry or "how to learn." According to Malcolm Knowles[12] SDL is a process "in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes." Knowles points out that there is convincing evidence that people who take the initiative in learning (proactive learners) learn and retain more than do people who sit at the feet of teachers passively waiting to be taught (reactive learners). They enter into learning more purposefully and with greater motivation. Knowles' popularized a four-step process for SDL:

1. Diagnose & formulate learning needs
2. Identify resources for learning
3. Choose and implement learning strategies
4. Evaluate learning outcomes

We have attempted to integrate this process throughout our project activities. This report describes our progress towards enabling students to develop skills that will enable them to practice life-long learning.

The New TriAD Curriculum

The new curriculum involves a complete overhaul of our Freshman, Sophomore and Junior level courses and emphasizes a balance between materials science and engineering principles. Traditionally, our curriculum has favored the science side of understanding the inter-relationships of materials processing, structure and properties, with less of an emphasis on engineering practices that design products. However, since approximately 80% of our graduates enter industry, we felt it was imperative that our students be well versed in the language and practices of applied engineering.

The *Freshman Experience* provides students with the opportunity to explore the inter-relationships of science, engineering and mathematics. It helps them to understand how to synthesize the principles from their technical support courses in calculus, chemistry and physics towards solving applied engineering problems. It gives them an introduction to the design method and they are challenged to design, build and test a solar-based hot water heater system to meet the needs of a local charity organization. The students get the opportunity to see how their efforts can positively impact their local community and develop an appreciation for the role of technology in improving society. The *Sophomore Experience* focuses on challenging students to consider sustainability factors when developing design solutions. The impact of material selection on a product's life cycle and cradle-to-cradle as well as "green engineering" design practices are studied. Projects involve evaluating the use of ecomaterials in common-day products (such as a coffee cup, cookware, disposable razor or home insulation), as well as the role of nanomaterials in living systems (such as an artificial organ).

The *Junior Experience* focuses students towards looking at design problems from a system-level perspective and challenges them to draw upon their mastery of the fundamentals to implement a technical solution that meets a set of user requirements. There are four projects that will be completed across the entire junior year and they are based on metallurgical, electronic, structural and hybrid materials systems. The goal is to integrate fundamentals covering thermodynamics, kinetics, electrical, optical and mechanical properties of materials into the design solutions. This paper will focus on the methodologies used for development of the projects, and implementation and assessment of the first two projects (metallurgical and electronic materials systems), which were completed in the fall 2006 quarter. Rather than individual lectures that meet 2-3 times per week, with corresponding lab sessions, junior-level students in the new curriculum meet every day for a 2-3 hour project session. Each day's activities are tailored to the needs of the project and may include open-time for team discussion and problem solving, learning activities, mini-lectures with Q&A sessions, computational analysis of data as well as fabrication and assembly of parts. There is no rigid schedule and the students work in teams composed of 4-6 students.

Design Methodology for PBL Activities

Seven faculty spent two weeks during the summer of 2006 to develop the PBL design activities for our Junior Experience. We followed a collaborative process for systematically designing each project-based series of activities as outlined below:

Step 1: We began by identifying a profile of our customer's needs and values. First we listed the values that our students have expressed over the years:

- Gain useful knowledge and skills
- Have fun
- Be treated with respect by instructors
- Have positive interaction with other students
- Achieve mastery relative to goals (competent in solving problems)
- Clear and fair course expectations, workload and grading
- Consistency between faculty
- Instant gratification
- Instructor should be all-knowing (guide, teach, clarify)
- Identify as a materials engineer (relate to what they do)
- Have input on direction of course (ownership)
- Functioning lab tools, equipment, resources

Using these values, we established several user profiles or personas that capture many of the characteristics that we believe are representative of our students. These user profiles were explored in some detail based on previous classroom experiences and interactions with Cal Poly students; a brief summary is presented here to provide a general sense of the differences in the individual users.

- *Joe Enginforium*
    - Wants to get an A
    - Domineering and likes to be in charge in team-based settings; has difficulty trusting his teammates with assigned tasks
    - Likes "canned assignments" and thinks "he-knows-it-all"
    - Prefers structure and guidance from faculty
    - Motivated to land an engineering position at a large firm and work his way up the corporate ladder
- *Krypton Uranis Orbito, II*
    - iPod-wearing surfer from southern CA

    - Generally enjoys hands-on engineering work, but stresses over performance in courses
    - Lacks confidence, particularly in the more quantitative engineering tasks
    - Interests outside of engineering include the environment, music, surfing, hiking
    - Disorganized and lacking in self-regulatory skills, but highly creative
- *Ms. Tiffany Spice*
    - Not motivated by high grades; content w C's
    - Average performance on traditional exams
    - Excellent interpersonal skills; loves working on teams
    - Confident about personal goals – wants balance between her career and family
    - Involved in many social activities, including the materials science professional society student chapter and other clubs
- *Wilbur Needy*
    - Transfer student from a local community college
    - Longs to succeed in engineering
    - Not able to self-assess needs or deficiencies
    - Quiet and works hard (but sometimes on the wrong stuff)
    - Inadequate background for immediate success in courses; needs guidance for success, but may be afraid to ask for help

As we developed the design activities, we examined the anticipated responses from these user personas in an attempt to understand how different students may react to the new materials engineering project courses. We strove to ensure that each of the needs and values of these student personas would be addressed, and that they all would be challenged to perform at their highest levels.

Step 2: We identified the *universal core competencies* that our curriculum must inspire our students to achieve. It is our desire that all our students achieve excellence in each of these areas:

- Communication (written & oral)
- Cognition/problem solving
- Business skills (e.g. economics, safety, IP)
- Lab skills/psycho-motor
- Teamwork
- Modeling/data analysis (statistics)
- Sustainability/life-cycle-analysis
- Design method
- Processing/fabrication
- Life-long learning skills

Step 3: We outlined the *major topics or categories* that must be covered during the completion of the design activities. It is our desire that all of our students be able to demonstrate a mastery of these topics:

- Crystallography/bonding/structure
- Mechanics
- Nanotechnology
- Composites
- Thermodynamics/phase transformations/diffusion (heat & mass flow)
- Biomaterials
- Design of experiments
- Materials characterization
- Material degradation (corrosion)
- Material selection
- Polymers
- Ceramics & inorganic glasses
- Process control
- Electrical, optical, magnetic properties
- Metals
- Computer tools, data acquisition, sensing

Step 4: Next, we made a list of all of the potential projects (design activities) that we felt were feasible and would cover the core competencies and major topics we outlined above. We mapped the student values, core competencies and major topics against our potential project list and narrowed down the list to the four projects that would cover all of these objectives. We targeted two projects (metal casting & light measurement system) for the Fall quarter (10-weeks), one project (hip implant) for the Winter and one project (hybrid product design – renovate Cal Poly Power House) for the Spring quarter. We also decided that if any project needed to "spill-over" from one quarter to the next, we would try to accommodate that eventuality if it was necessary for a successful completion of the project.

Step 5: For each project we established an objective, deliverables and a timeline (Gantt Chart) of activities (tasks) with resource requirements. Developing a detailed project Gantt Chart turned out to be a very valuable asset during the Fall quarter as it kept all of us focused on the overall objective and allowed for the student teams to manage their time according to each milestone (e.g. design reviews). We established a website with weekly reading assignments for the students along with study questions that would support the development of self-directed study habits. Quizzes based on the reading assignments were completed by individuals and by teams as a whole and the class decided the balance of weighting (individual vs. team performance) that would be applied to their final grades. All design reviews were evaluated orally according to a grading rubric, which included self-assessment, peer-assessment and instructor-assessment. Product brochures were developed for the metal casting project and a final written project report was completed by each student for the light measurement system.

Implementation of Fall Quarter Projects

After exploring many options for the fall quarter of the junior-year experience, we settled on two projects: a metal casting project and a light measurement system project. The first involves design and fabrication of a cast metallic personal artifact that represents the values of the engineering department at Cal Poly. The second project required students to development a light measurement system for characterizing optical filters. Both projects are briefly described in the following sections.

Metal Casting Project: The casting project lasted approximately four weeks and challenged students to examine the inter-relationships among an alloy material's structure, processing and properties. For example explaining and predicting the microstructural changes that occur as a result of thermal processing then connecting this to measured harness values for the cast objects. This project involved the use of 3D-conceptual modeling software (SolidWorks) and rapid prototyping techniques (Z Corp 3D Printing w/starch & wax or Stratasys w/ABS) to design and fabricate a mold, as shown in Figure 1. Students could choose from a limited number of alloys (silicon bronze, Zn-Al, or Al-Si) and were asked to analyze the impact that the fabrication processes (see Figure 2) would have on the surface finish and determine the appropriate tolerances for the dimensions of the final object. Thirty-nine junior-level students were divided into six teams for the metal casting project.

Figure 1 – Sprue patterns generated by rapid prototyping in ABS material

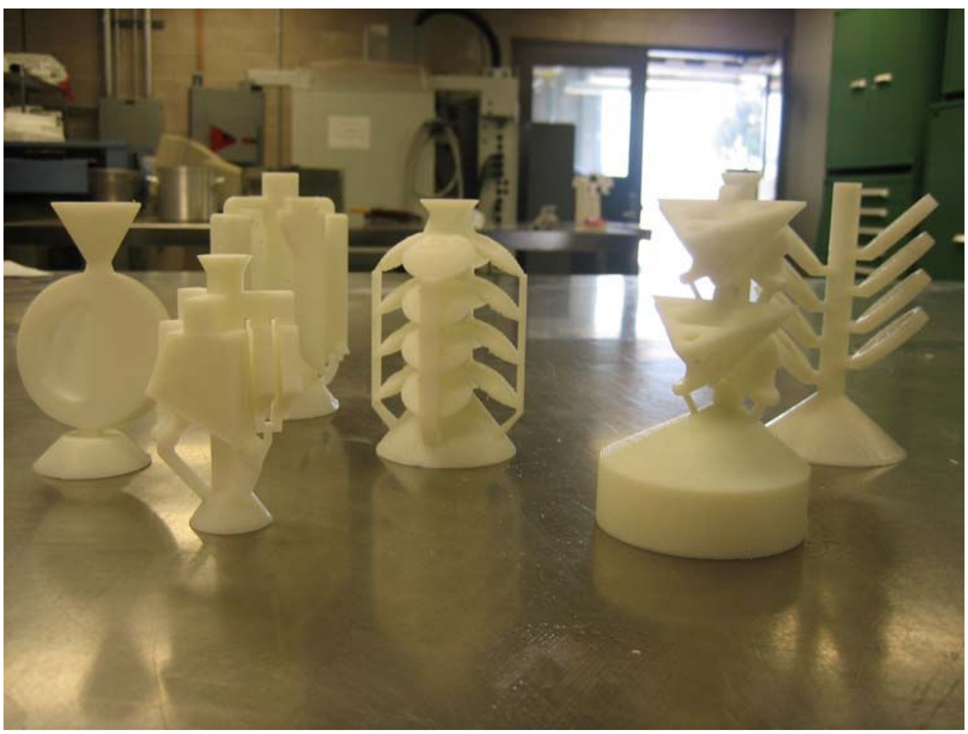

Figure 2 – Pouring of metal casting by students

Light Measurement System Project: The light measurement system project required students to optimize their design to achieve a light throughput that would produce an optimum signal to noise ratio at the detector. The student teams designed and fabricated a measurement system that would transfer light from a source through optical fibers to a sample holder, collimate the light and send it through the sample filter. The light was then collected and sent via an optical fiber to a spectrometer for wavelength separation and detection by an array of photodiodes. The performance of each component had to be carefully optimized in order to achieve the user's defined precision and accuracy for characterizing the optical filter's performance, as shown in Figure 3. Electrical, optical and mechanical components were integrated together as a system and the impact of design specifications on fabrication costs were carefully evaluated. A work breakdown structure was developed for the project and each team utilized a Gantt chart to monitor their progress and manage the assignment of tasks between different team members. Thirty-three students were divided into five teams for the light measurement system project.

Figure 2 – Students characterizing optical filters with light measurement system they built

These projects required students to develop self-directed learning skills in order to solve the many design problems that they faced. The progressive development of SDL skills throughout the curriculum is a key metric that can indicate the effectiveness of our PBL pedagogy. A self-rating assessment technique was employed to track the development of the students and the results will be discussed in more detail later in this paper.

The *Senior Experience* has remained largely unchanged and students can choose from a range of technical elective courses that promote balancing depth and breadth and foster professionalism. Courses include subjects such as Biomaterials, Microfabrication, Micro Systems Technology, Failure Analysis, Material Characterization and Corrosion. The capstone course, entitled “Corporate Culture,” gives students an overview of how to practice engineering in the corporate world and covers topics such as organizational structures, product development processes, corporate business models, intellectual property, ethics and the practice of life-long learning. Moreover, each student must complete a Senior Design Project and present their findings at the annual Materials Engineering Technology Conference.

Assessing Our Progress

One of the continuing challenges of any pedagogy is developing direct measures of student performance against learning objectives. This challenge exists with the project-based method as well and is, in some senses, made more challenging by the fact that students' individual contributions to "team" performance are often unclear. We assessed the performance of the junior-cohort of materials engineering majors in a project-based learning curriculum against a comparable junior-cohort (engineering majors) at Çal Poly that was presumably exposed to a more conventional curriculum. The cohort in the project-based learning environment scored significantly higher in intrinsic motivation and identified regulation, two types of motivational factors that have been shown to result in greater use of self-regulated learning strategies. They also report a higher degree using of peer-to-peer learning strategies than their cohort in conventional curricula. The details of these research results are reported elsewhere[13].

We also compared the response of the junior-cohort (materials engineering) in the project-based curriculum to those of seniors in materials engineering who did not have the intensive project-based learning curriculum. Both cohorts were at Cal Poly, but the junior class experienced the curricular phase-in of the project-based learning methods. The following sections describe the differences in the cohort responses.

Student Responses to Learning Environment and Format

The initial student responses to the new learning environment have been overwhelmingly positive. The main concerns are that the teams are too large (currently 6-7 students per team) and that there is not enough time to develop the depth of technical knowledge required to demonstrate a mastery of the fundamentals. We have adopted an assessment strategy employing a modified version of the Knowles self-rating scale for evaluating self-directed versus teacher-directed modes of learning[12]. Our primary focus in this report is the students' perception of their self-directed learning skills. This is one of the core skills that enables life-long learning, and one that a student must demonstrate in order to be successful as a global engineer in the 21st century.

Our hypothesis was that students who learned in a project-based based learning environment (juniors, in this case) would report a higher degree of comfort with self-directed learning strategies than those who did not (seniors, in this case). For our study, we used a quasi-control group consisting of engineering students from the same major at the same institution (Cal Poly). However, the test group (juniors) has experienced the phase-in of the new TriAD curriculum, whereas the quasi-control group (seniors) has experienced a more conventional Cal Poly curriculum. We should note that our department has made a concerted effort to integrate active-learning modes into Cal Poly's "hands on" learning environment for the past eight years, so the learning modes for the senior cohort already has a great degree of problem-based, active learning within the curriculum. Both groups were admitted to Cal Poly under the same criteria and are statistically equivalent in terms of their academic qualifications.

To evaluate the differences in cohort response to the learning environment, both cohorts completed a questionnaire based on the one developed by Knowles. Table 1 shows the means for each of the responses from the junior (33 students) and senior (21 students) cohorts along with p-values (one-tail) calculated by a t-Test assuming unequal variances. Questionnaire items in bold text indicate items in which the junior test cohort scored higher than the senior quasi-control cohort at a significance level of less than 0.05 (i.e., using a 95% confidence interval).

Table 1 - Self-Directed Learning Self-Assessment Evaluation
Based on Knowles (1975)

Disagree - 1	Disagree Somewhat - 2	Unsure- 3	Agree Somewhat - 4	Agree - 5	$X_{juniors}$	$X_{seniors}$	P value
1. I understand the differences between teacher-directed learning and self-directed learning.					4.73	4.48	0.050
2. I understand the differences in skills required under teacher-directed learning and self-directed learning.					4.27	4.19	0.331
3. I am able to explain the differences between teacher-directed and self-directed learning.					4.30	3.86	0.006
4. I consider myself a non-dependent and a self-directed person					4.15	3.55	0.013
5. I am able to relate to peers collaboratively.					4.61	4.43	0.188
6. I see my peers as resources for helping me plan my learning.					4.13	3.95	0.253
7. I see my peers as resources to help me know what I need to learn.					4.09	3.71	0.119
8. I see my peers as resources for my learning.					4.50	3.95	0.042
9. I give help to and receive help from my peers.					4.72	4.19	0.023
10. I am able to realistically diagnose what I need to learn.					3.97	3.86	0.319
11. I am able to realistically diagnose what I need to learn, with help from my teachers and peers.					4.64	4.25	0.009
12. I am able to identify my learning needs.					4.15	3.95	0.179
13. I am able to set learning goals for myself.					4.00	4.10	0.351
14. I am able to recognized when I have attained my learning goals.					4.33	3.90	0.045
15. I am able to relate to teachers as facilitators, helpers, and consultants.					4.58	4.10	0.013
16. I am able to take initiative in making use of resources provided by my teachers.					4.24	3.76	0.027
17. I am able to identify the appropriate people to help me attain my learning goals.					4.64	4.05	0.002
18. I am able to identify appropriate material resources (e.g., books, software, hardware, library) to help me attain my learning goals.					4.52	3.90	0.006
19. I am able to create a plan for making use of learning resources (e.g., instructor, books, etc.).					4.12	3.81	0.121
20. I am able to initiate a learning plan that I designed.					4.00	3.38	0.010
21. I am able to complete a learning plan that I designed.					4.03	3.33	0.013
22. I am able to effectively manage my time in a self-directed learning environment.					3.70	3.38	0.178
23. I am able to evaluate the strengths and weaknesses of my learning plan.					3.70	3.81	0.353

24. I am able to provide evidence that I have learned what I needed to know.	4.06	3.74	0.097
25. I am able to accurately evaluate whether I have learned something.	4.27	3.90	0.049
26. I am able to identify the usefulness of what I am learning	4.27	4.29	0.477

Compared to materials engineering seniors, the junior-level students who completed the new projects reported better recognition of the differences between traditional, teacher-directed learning environments and those that emphasize student control. Juniors seemed to be more comfortable with accepting, that the role of the teacher, should be to serve as a facilitator and not as a walking encyclopedia. The statistically higher scores for question 4 indicates that they appear to have higher perception of themselves as autonomous learners. Given that the data represents student perceptions after completion of only one-third of the junior-level materials engineering projects we find this to be an encouraging trend.

Both the juniors and the seniors struggle with being able to diagnose their learning needs and sometimes need help developing methodologies for finding the right resources for learning the fundamentals. This may be an interesting direction to explore in greater depth in the future. A more detailed examination of the student responses to the learning goals and an investigation of the factors that students find helpful in diagnosing their learning needs should be developed. Activities and feedback mechanisms should be incorporated which would allow students to adjust project goals and directions in any direction that would enable them to develop their skills as autonomous learners. Significantly, the responses to question 18 indicate that compared to the materials engineering seniors, the juniors who completed the open-ended projects seem much more comfortable with identifying learning resources that helped them to attain their learning goals. Identifying the value and relevance in what they are learning is an important factor in determining their motivation, interest, and engagement in learning. One of the key goals of the PBL materials engineering curriculum was the provision of a learning environment with strong connections to contextual factors. We believe that the emphasis on context in the PBL environment has helped students identify the practical importance of their learning, and that this ability will serve to bolster their engagement and motivation in the remaining junior-level projects.

Challenges of Transitioning to PBL Courses

There are a number of challenges that we have experienced while trying to implement PBL activities. These activities are resource intensive both in faculty time and design materials. The demands on faculty time, particularly during the developmental and first-time implementation phases, are significant. Effective implementation and fostering of a collaborative, faculty team environment requires regular sharing of ideas, frequent discussion of approaches and assignments, and attendance of all involved faculty to most of the project sessions. Multiplexing the daily activities requires 2 full-time faculty at a minimum.

Assessment (assigning a grade), particularly at the individual level, is difficult since the majority of the work is team-based. Another challenge is maintaining the right balance between the depth and breadth of the knowledge that our students will need to be successful. Funding the projects can be difficult although we are seeing an increase in corporate partnerships and donations specifically to support PBL activities. Supporting the wide range of equipment necessary to complete the projects is also challenging, but we have utilized graduate students as teaching assistants and found this to be most effective. It gives our graduate students a chance to practice project management techniques.

The PBL process requires students to be very self-directed in their learning and to take "ownership" of their own education. Confident students are able to do this but many students do not know how to find and distill the information down to the principles required to solve problems. Probably the most important challenge is to develop methods that students can use to organize, synthesize and incorporate selected information into their knowledge base. This includes finding relevant information pathways and tools such as books, technical articles, review articles, patents, encyclopedias, handbooks and on-line data bases as well as determining the right level and depth of information required. Care must also be taken to select projects that do not present too complex a learning environment. If too many principles must be assimilated at once, students can become frustrated and this can dilute the learning experience. Projects must be based on problems with achievable solutions. Students also need to see the relevance of the problem. If the project is not "interesting," students will not put as much effort into finding a solution. It is challenging to come up with projects that capture the interests and motivation of the entire class.

Summary

We designed and implemented a series of project-based learning courses using an approach attempts to focus on the learners' needs. The design methodology began by creating profiles of the learners and their needs. Core competencies were then established for the curriculum, followed by listing major topics that need to be addressed. We then identified potential projects that could incorporate that major topics. Each project-based experience was then mapped out detail, ensuring consistency with major topics, core competencies and user profiles. However, our link to user profiles was not as strong as the others. Addressing user profile needs could have mitigated some of the student concerns about the changes in course format. Comparison of the responses of the test cohort to those of a quasi-control group indicated that the test cohort reported a significantly higher degree of comfort in the project based learning environment compared to the quasi-control group, scoring higher on 13 out of the 26 items on the self-directed learning questionnaire. Because these differences are students' perceptions of their abilities, direct measures of abilities are needed to confirm whether the test cohort is in fact more capable of self-directed learning. However, the data indicate that the project-based learning format does result in a significant difference of student perception of themselves. Student in the project-based learning course format perceive themselves as more independent and self-reliant, more able to direct their learning than those in the more conventional engineering course format.

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